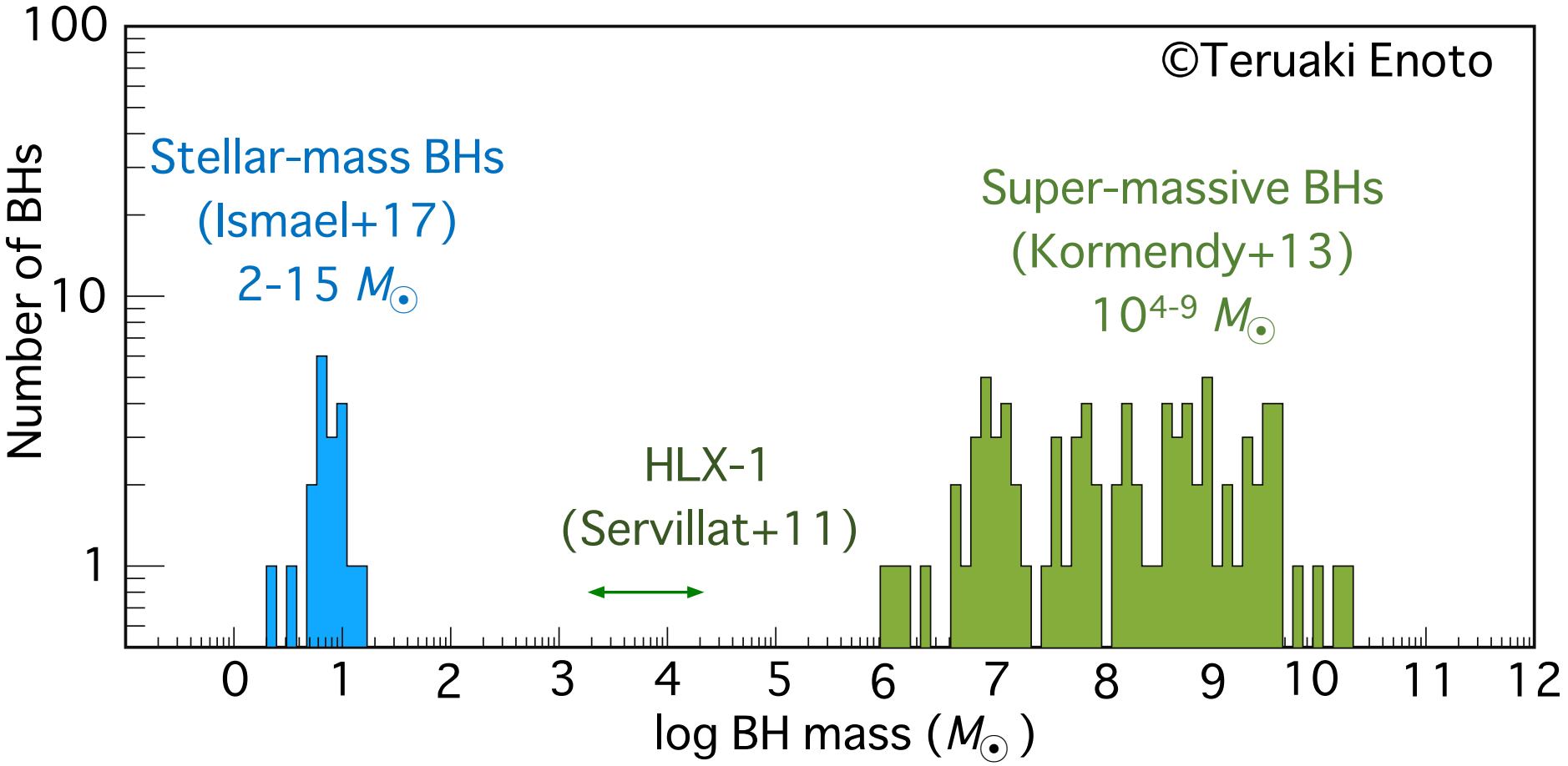
中間質量ブラックホール候補の超高光度X線源における新たな降着描像

A New Accretion Scenario for an Intermediate Mass BH Candidate: Ultra-Luminous X-ray sources

東京理科大学 (Tokyo University of Science)
小林翔悟 (Shogo B. Kobayashi)
shogo.kobayashi@rs.tus.ac.jp

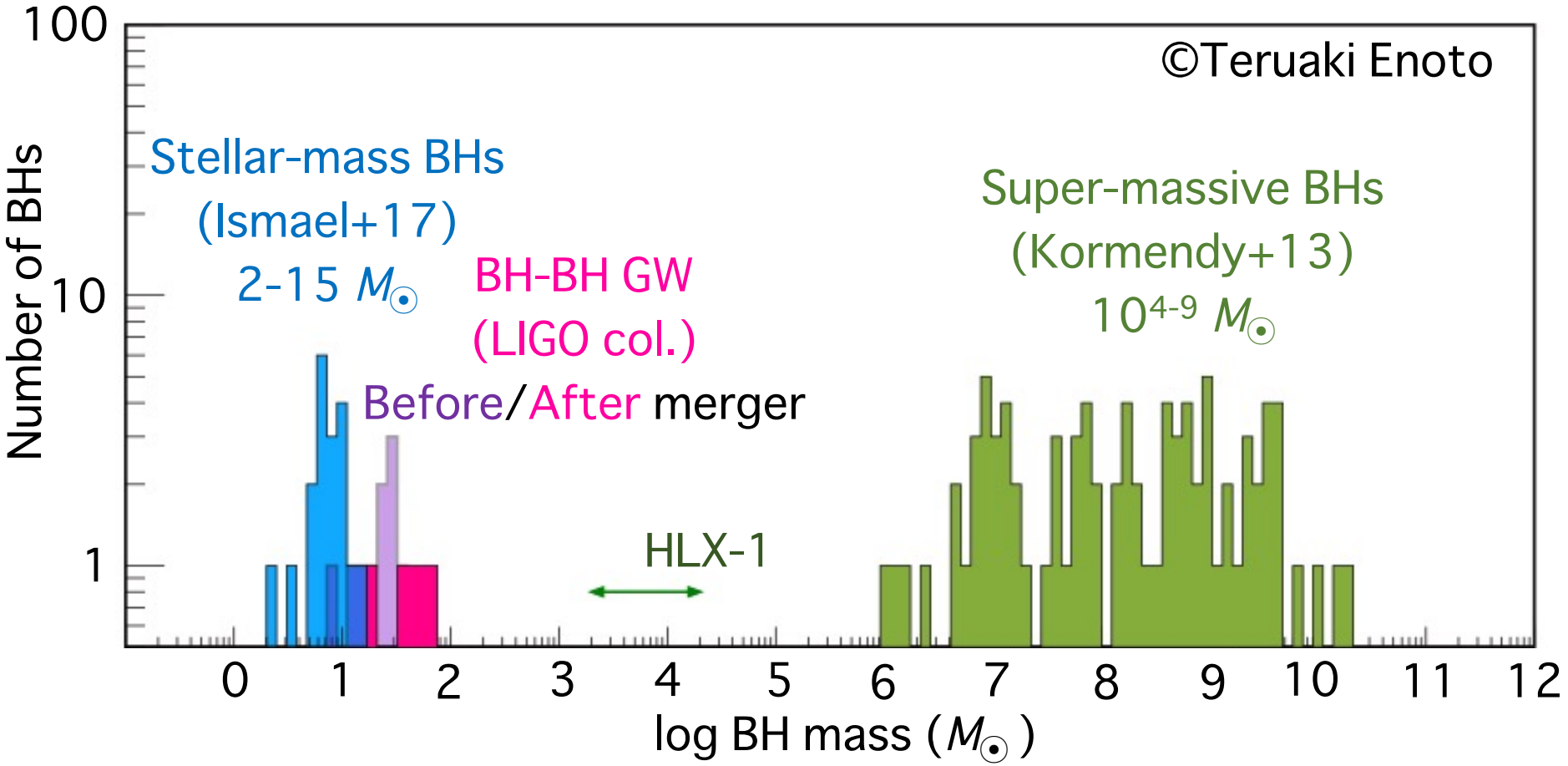
The present work is submitted to MNRAS as
"A New Possible Accretion Scenario for Ultra-Luminous X-ray Sources"
S. B. Kobayashi, K. Nakazawa, K.Makishima, 2018

Distribution of the Black Hole (BH) Mass



- LIGO has finally revealed the existence of BHs heavier than 15 $M_\odot$
- X-rays from such BHs (or even more massive ones) can be expected just like the other accreting BHs.

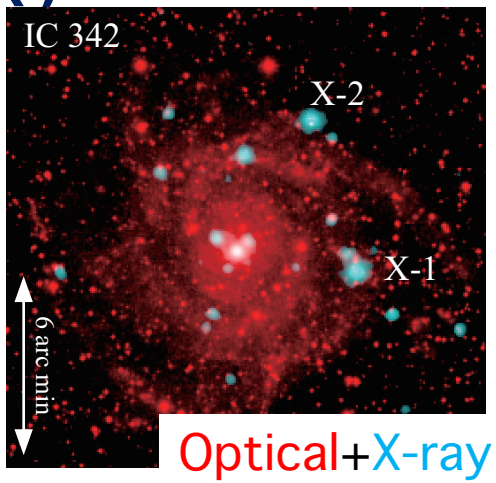
Distribution of the Black Hole (BH) Mass



- LIGO has finally revealed the existence of BHs heavier than 15 $M_\odot$
- X-rays from such BHs (or even more massive ones) can be expected just like the other accreting BHs.

Ultra-Luminous X-ray source (ULX)

- Luminous X-ray sources in other galaxies.
- $L_X > 10^{40}$ erg/s > L_{edd} of 10 $M_\odot$ BHs.
- Except for 3 sources, neither their central object masses nor accretion mechanisms are known.
  ~100 $M_\odot$ BHs with $L_x/L_{edd} \leqq 1$ (Makishima+00)?
  ~10 $M_\odot$ BHs with $L_x/L_{edd} >> 1$ (Mineshige+00)?

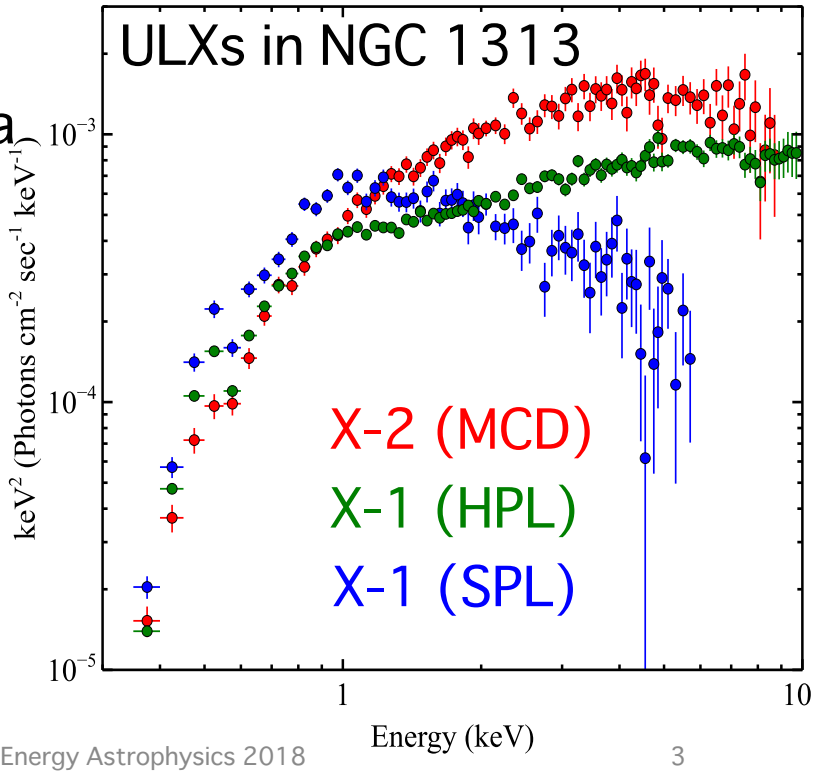


Optical+X-ray

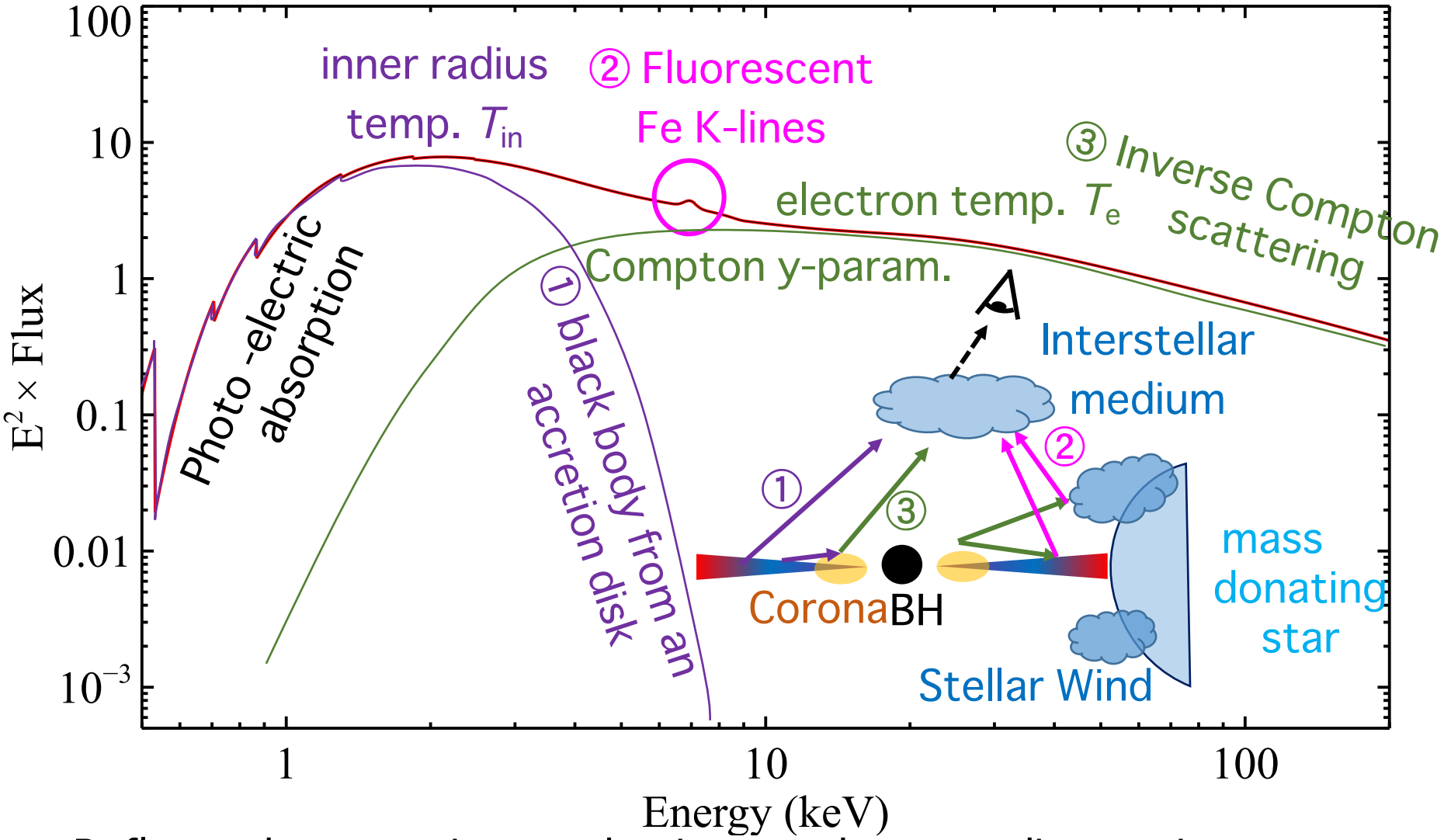
X-ray Spectra

- Exhibit three distinct types of spectra (e.g., Gladstone+09)
  Multi Color Disk like (MCD) state
  Hard Power Law (HPL) state
  Soft Power Law (SPL) state

- Comparing these with those of the well studied BH binaries (BHBs) should give clues to the problems.

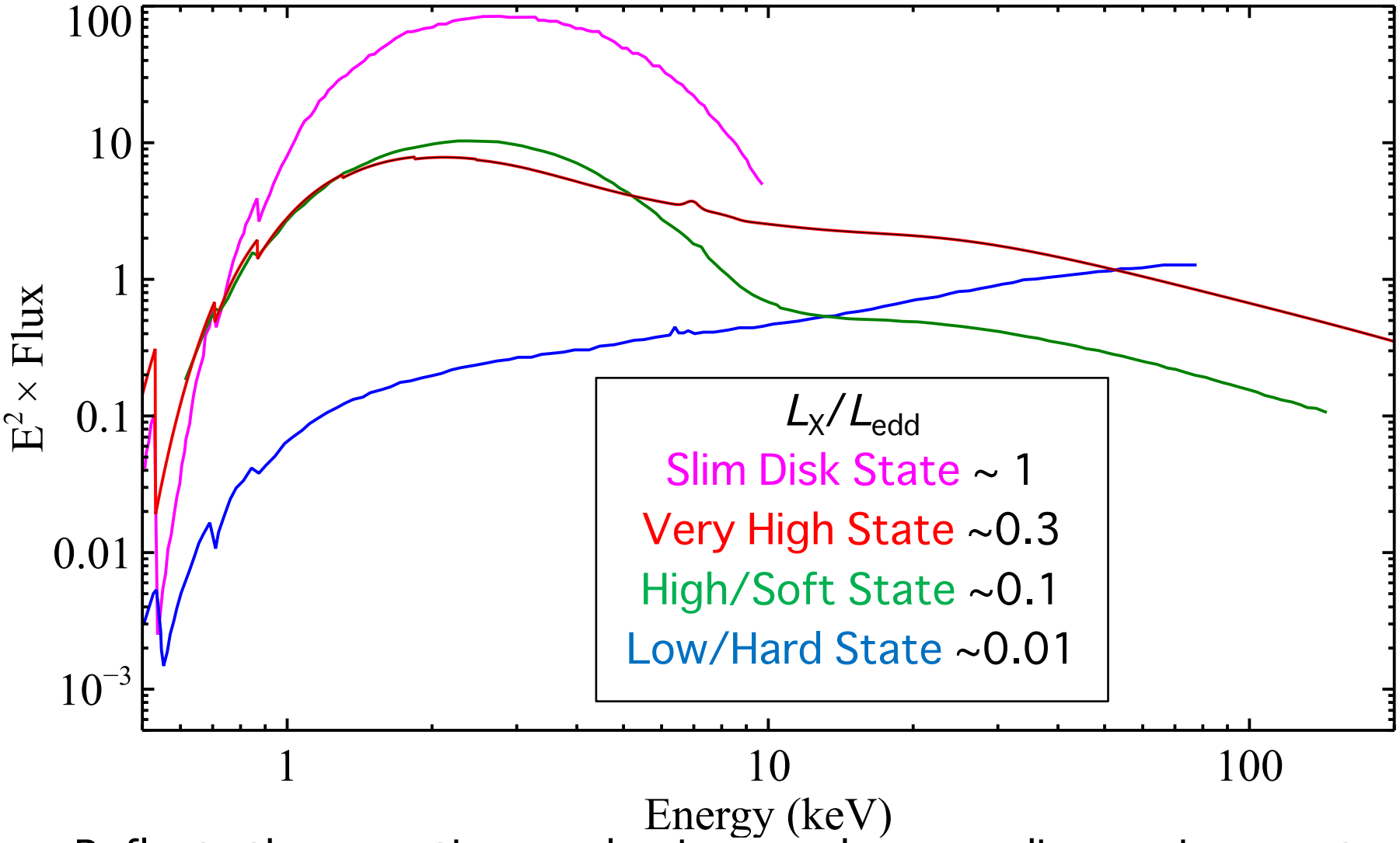


General Spectral Properties of Accreting BHs



- Reflects the accreting mechanisms and surrounding environments.

General Spectral Properties of Accreting BHs



- Reflects the accreting mechanisms and surrounding environments.
- Distinct states emerge as a function of L_X/L_{edd}

Objectives and Methods

Objectives

A) Study the distribution of critical luminosity where the certain spectral states arise (estimate the range of BH mass).

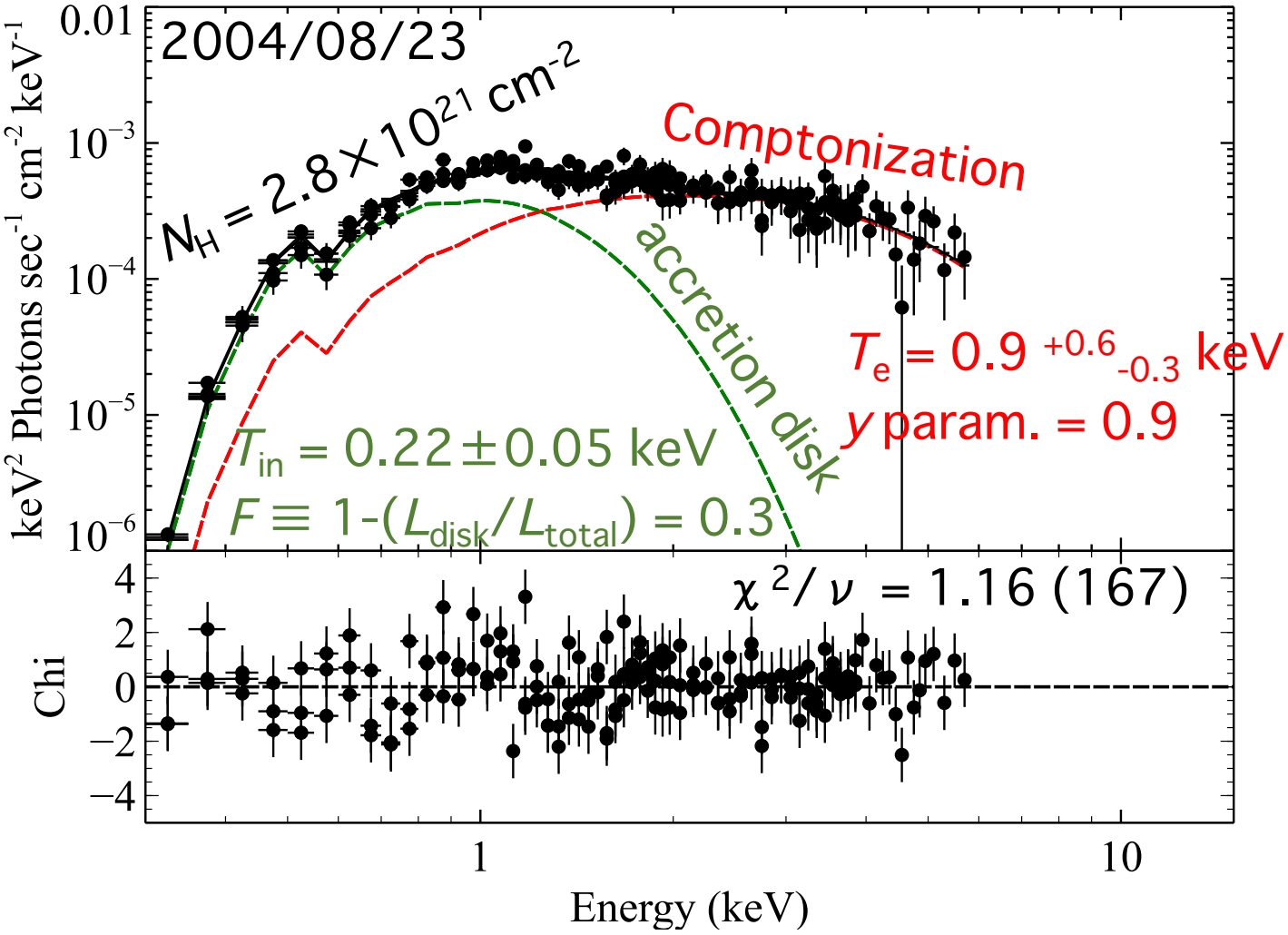
B) Examine whether the three states of ULXs correspond to either of the state of BHB (estimate the actual L_x/L_{edd}) .

C) Estimate possible accretion mechanisms/environment that explain the observed strength of Fe-K lines and absorption.

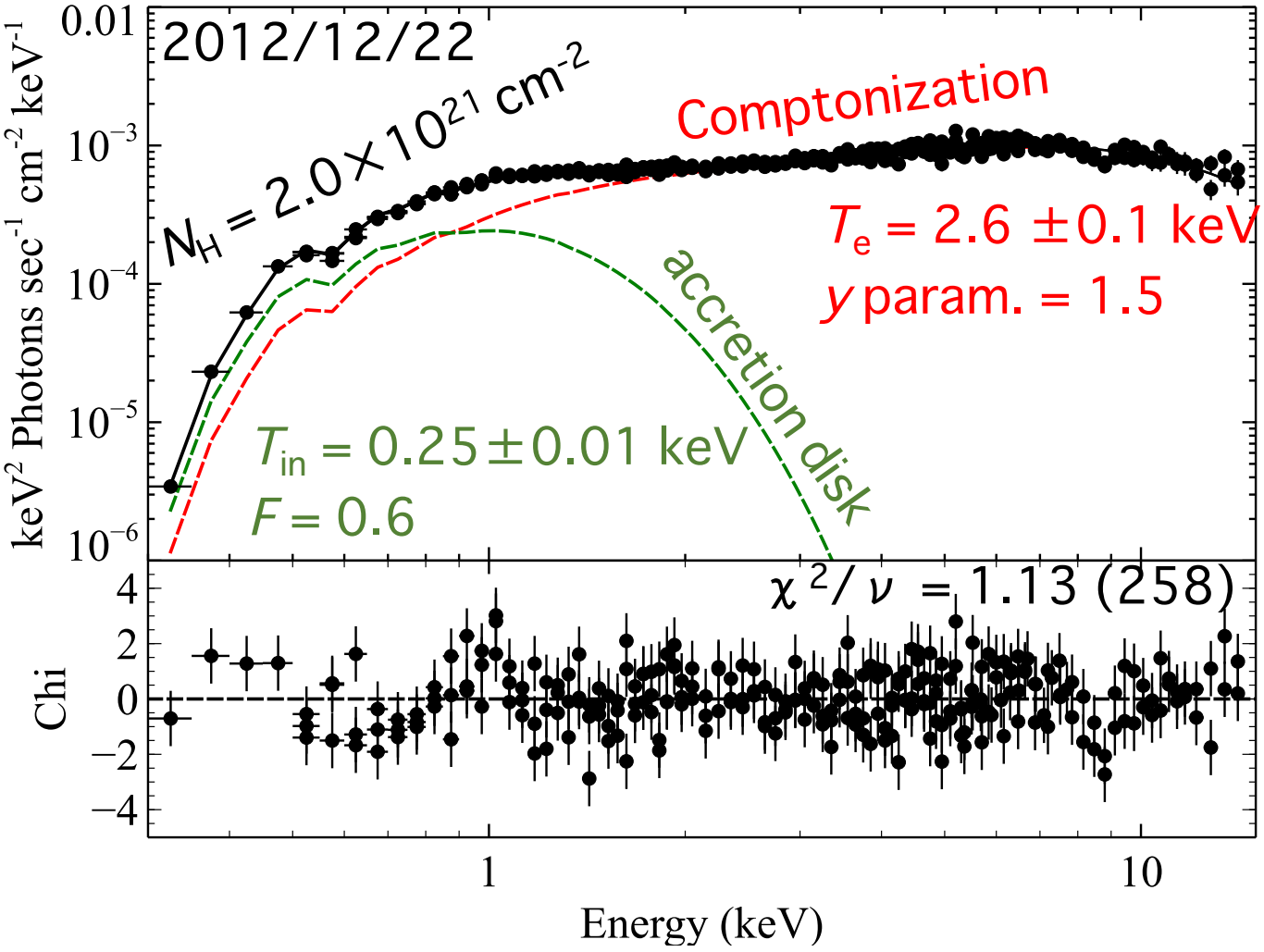
Methods

- We analyze the archival data of *Suzaku*, *XMM-Newton*, and *NuSTAR.*
- 9 representative ULXs in nearby (< 5 Mpc) galaxies are selected.
- We fit 56 spectra with a model widely used in BH studies (accretion disk emission+ thermal Comptonization; MCD+THC) to characterize the spectral shape in a quantitative way.
- Compare the results with those in the ordinary accreting systems.

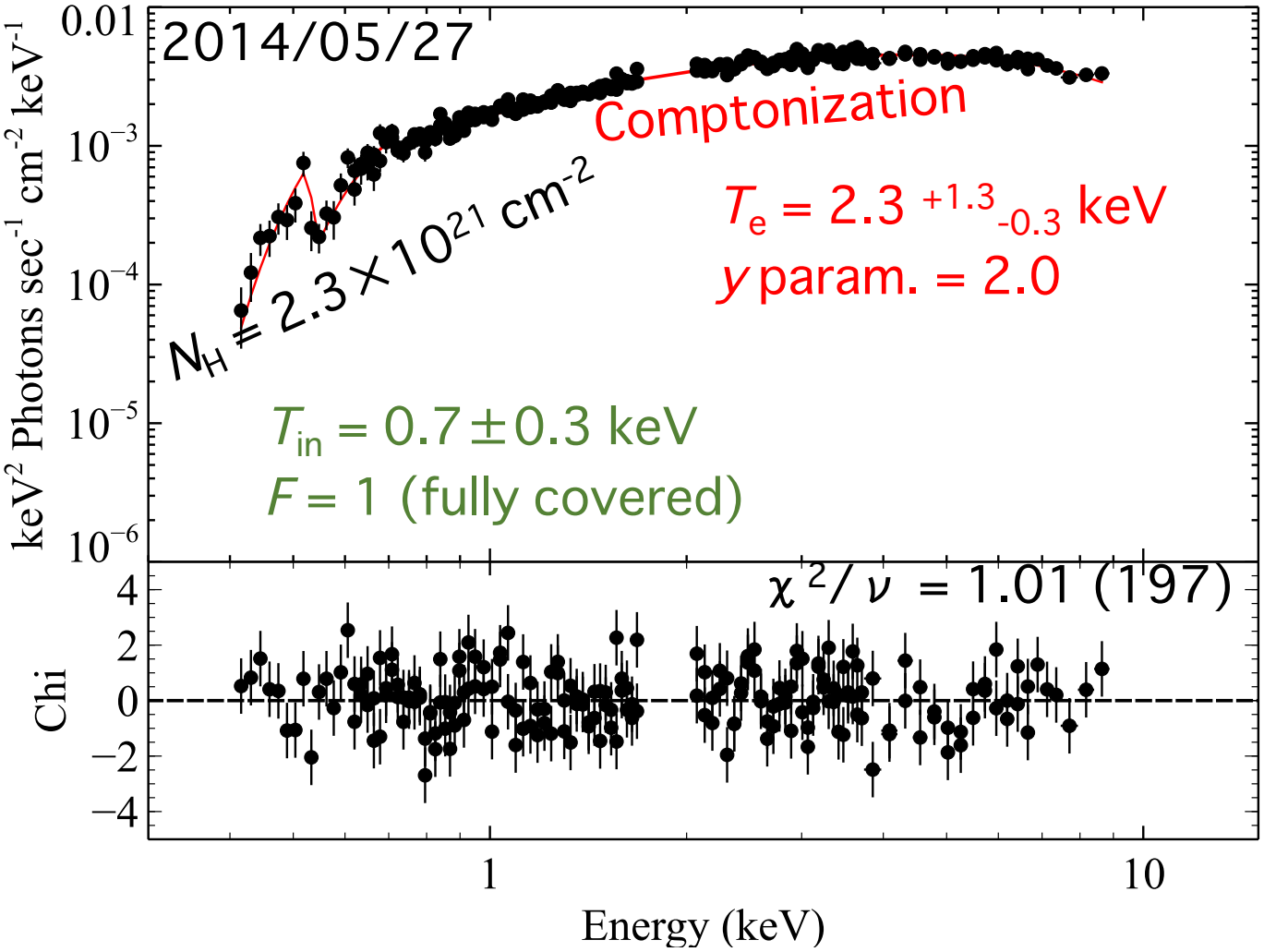
Spectral Fitting (NGC 1313 X-1 SPL state)



Spectral Fitting (NGC 1313 X-1 HPL state)

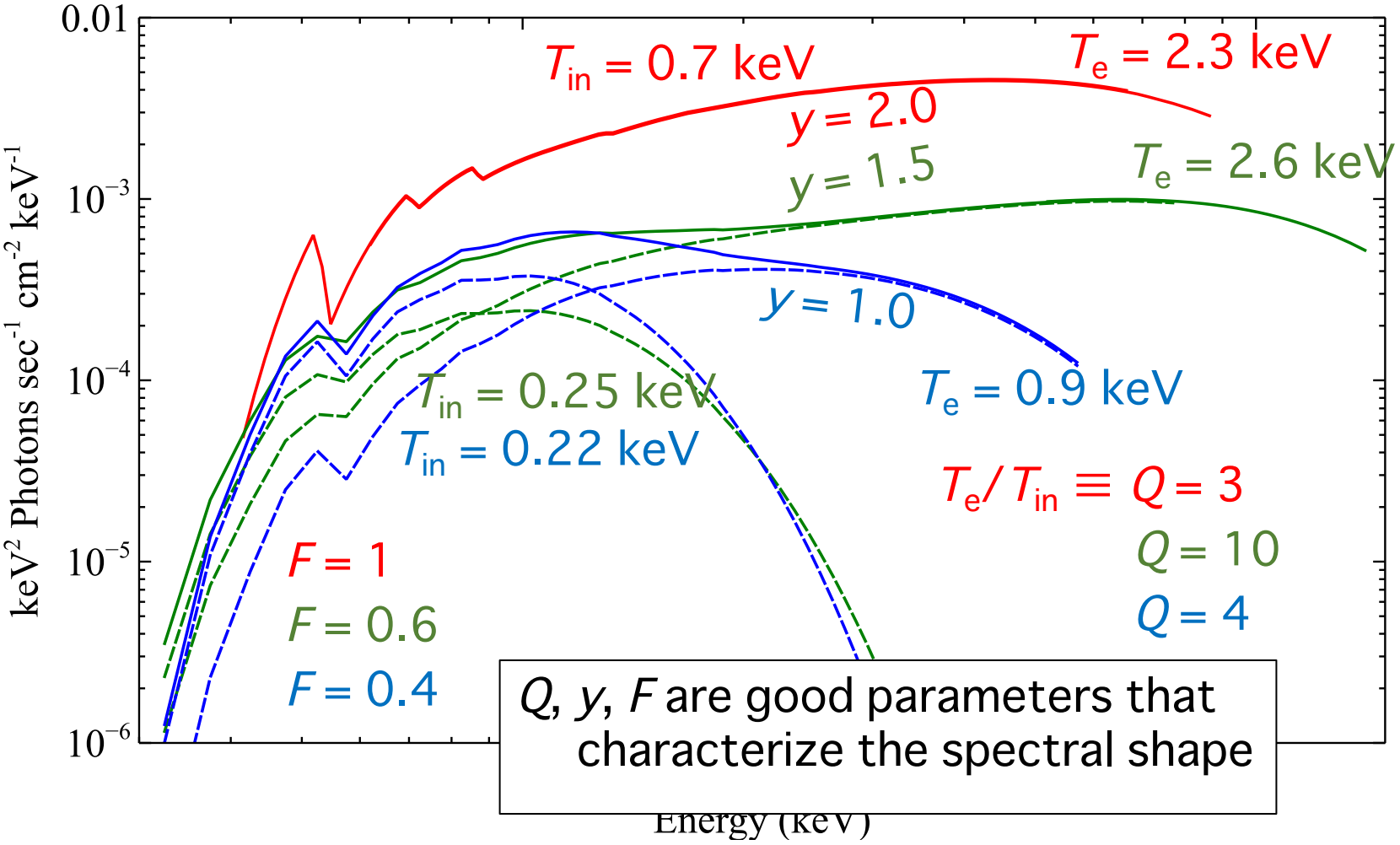


Spectral Fitting (NGC 1313 X-1 MCD state)



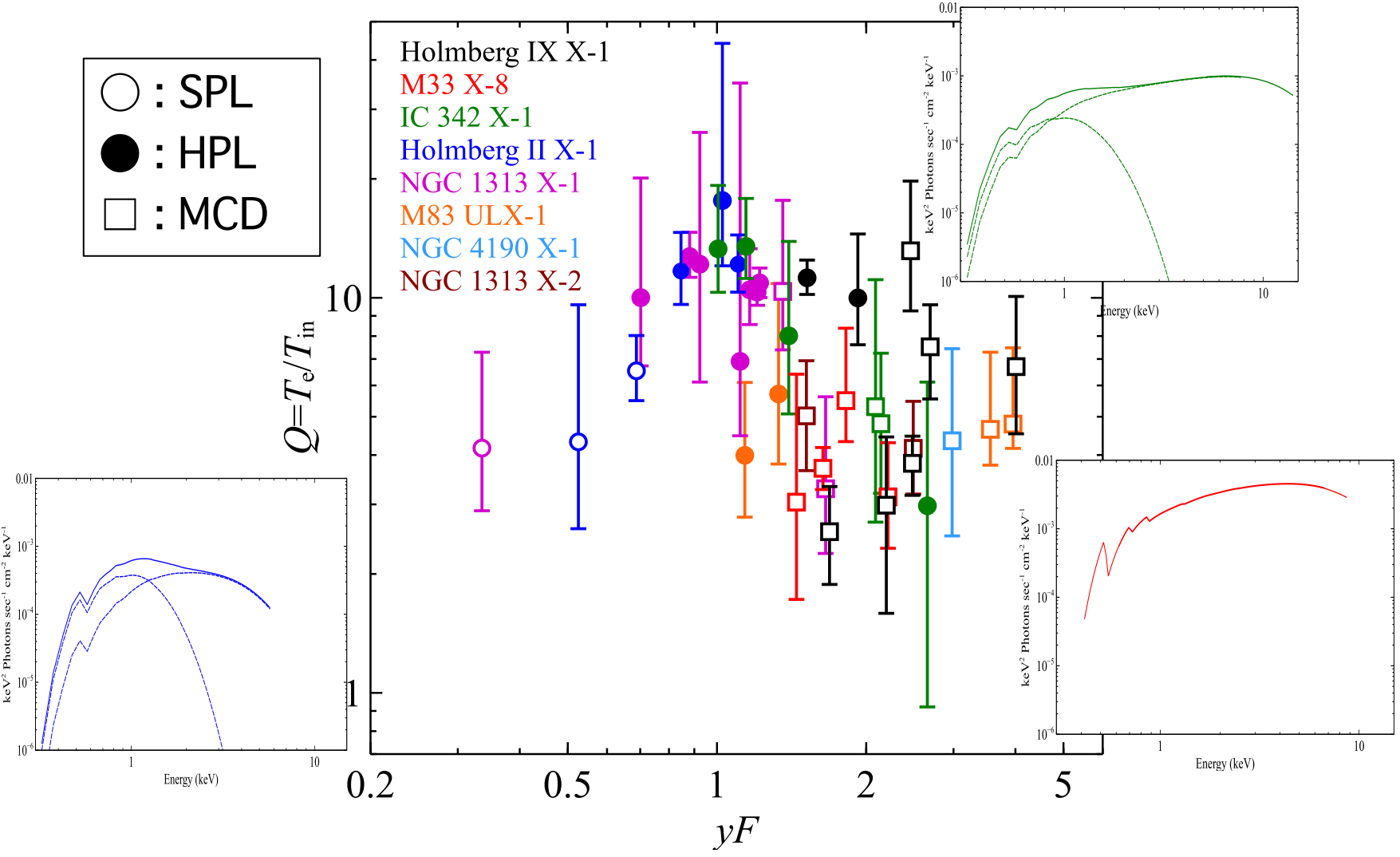
- All spectra are successfully explained with the MCD+THC model.
- No significant Fe-K line or drastic change in absorption are detected.

Characterization of the Three States



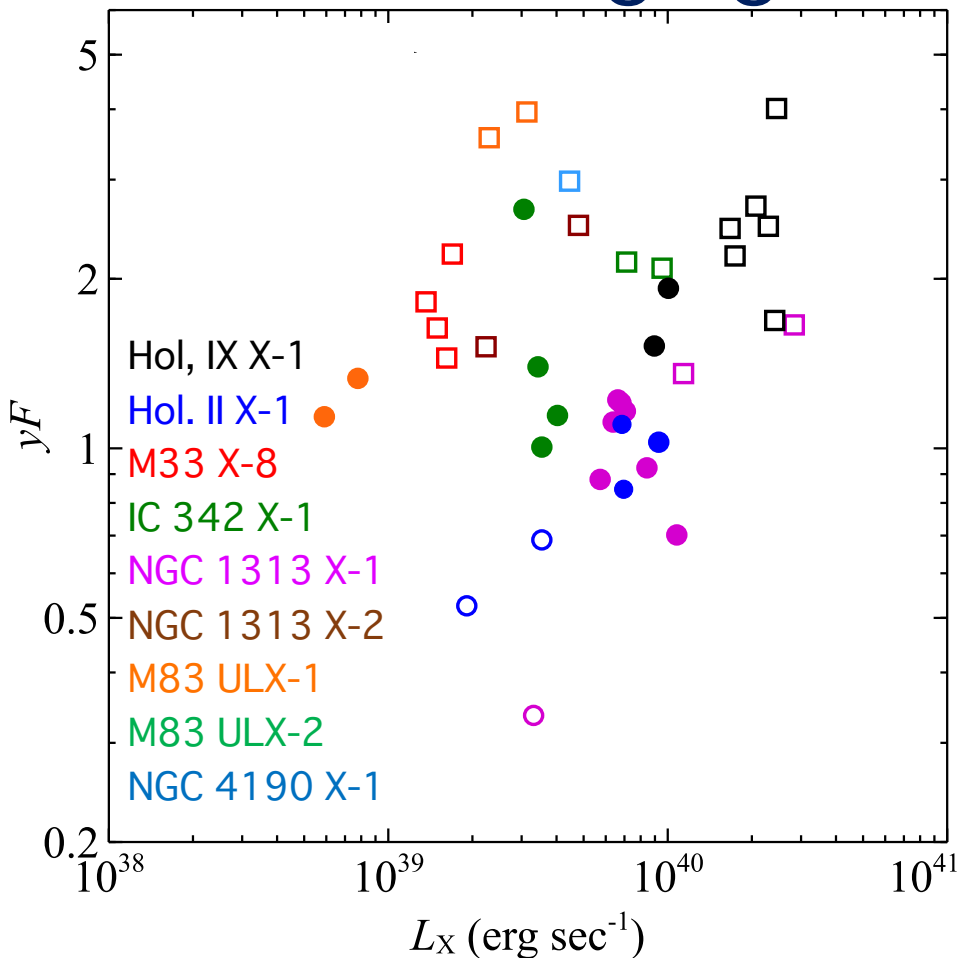
Q, *y*, *F* are good parameters that characterize the spectral shape

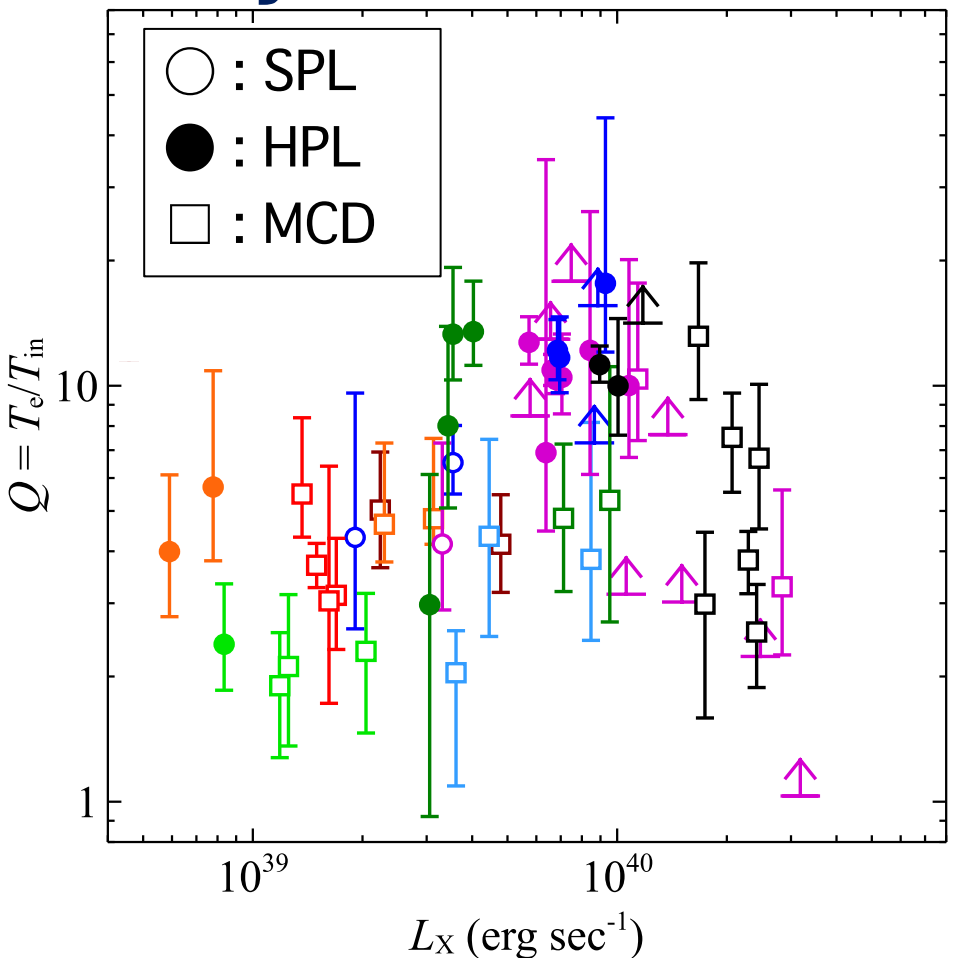
Characterization of the Three States



- The spectral shapes of the individual states are quantitatively characterized in terms of *Q* and *yF*.

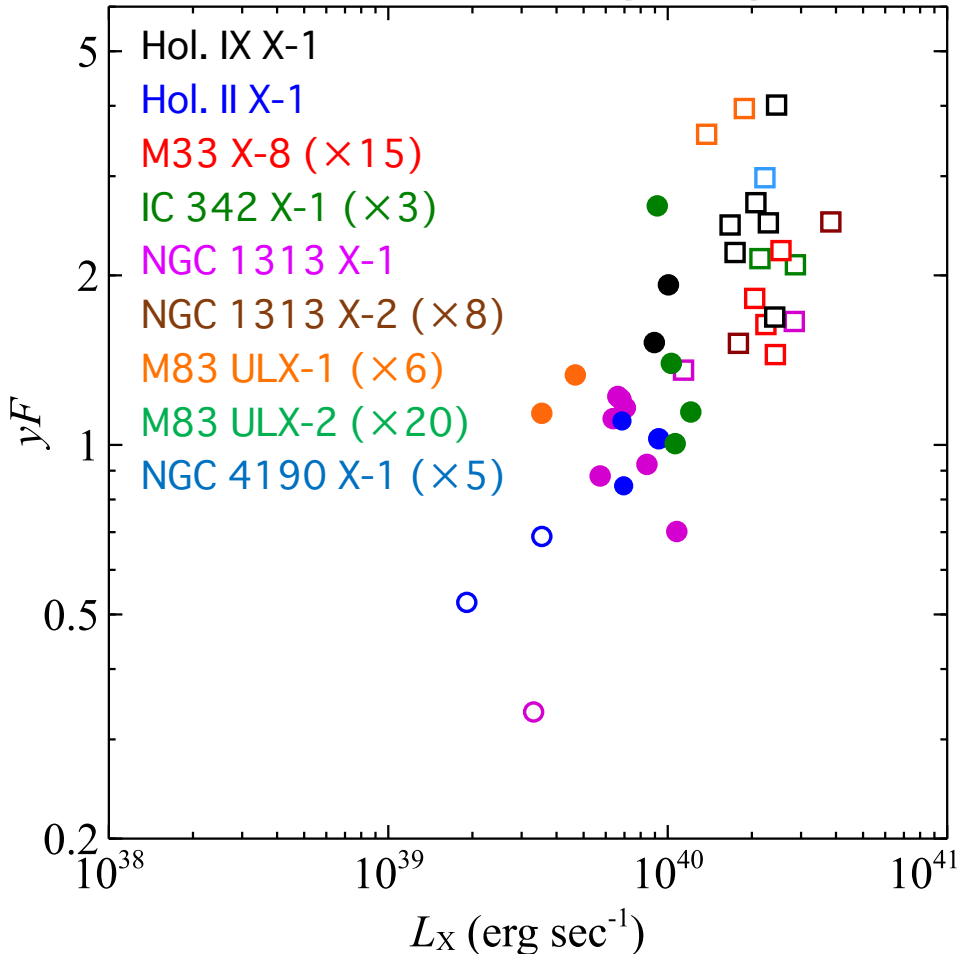
A. State Emerging Luminosity

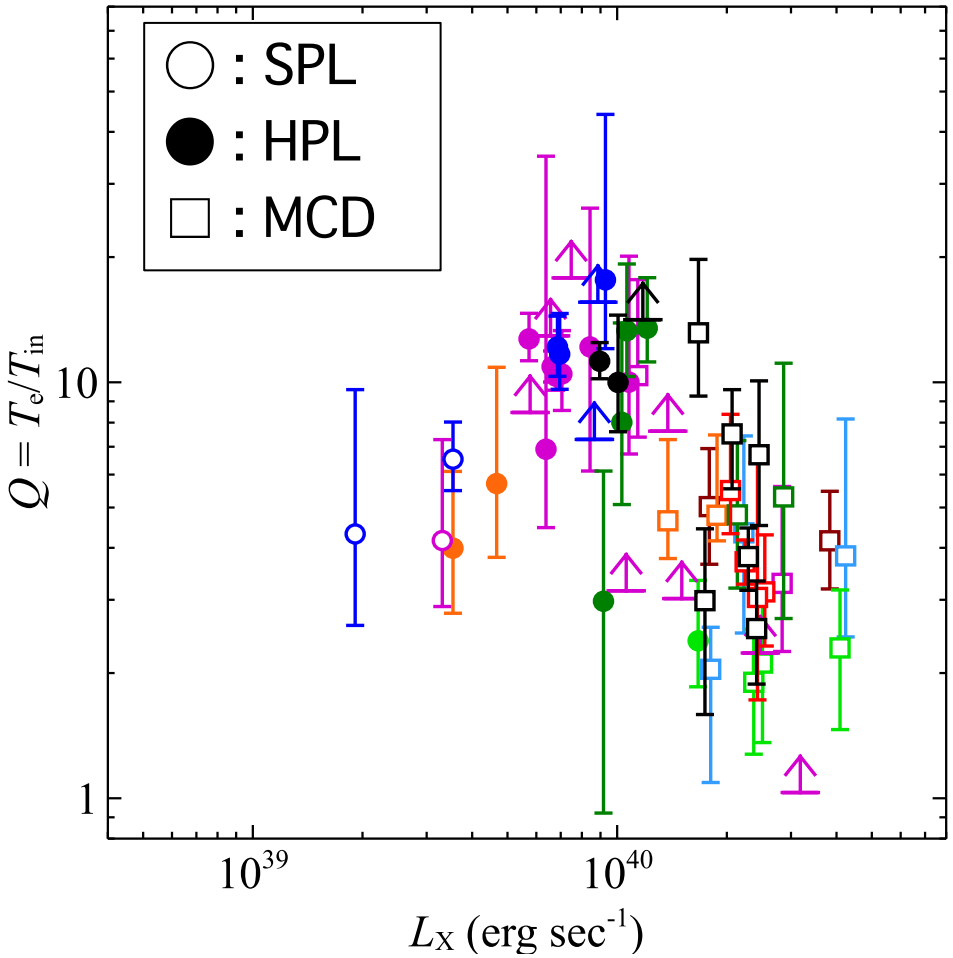




- The state-emerging luminosity scattered by a factor of 20.
- If the general properties of the accreting objects are also held in ULXs, then their BH mass should also have similar range.
- If we assume 10 $M_\odot$ as the minimum, the maximum will reach 100 $M_\odot$

A. State Emerging Luminosity

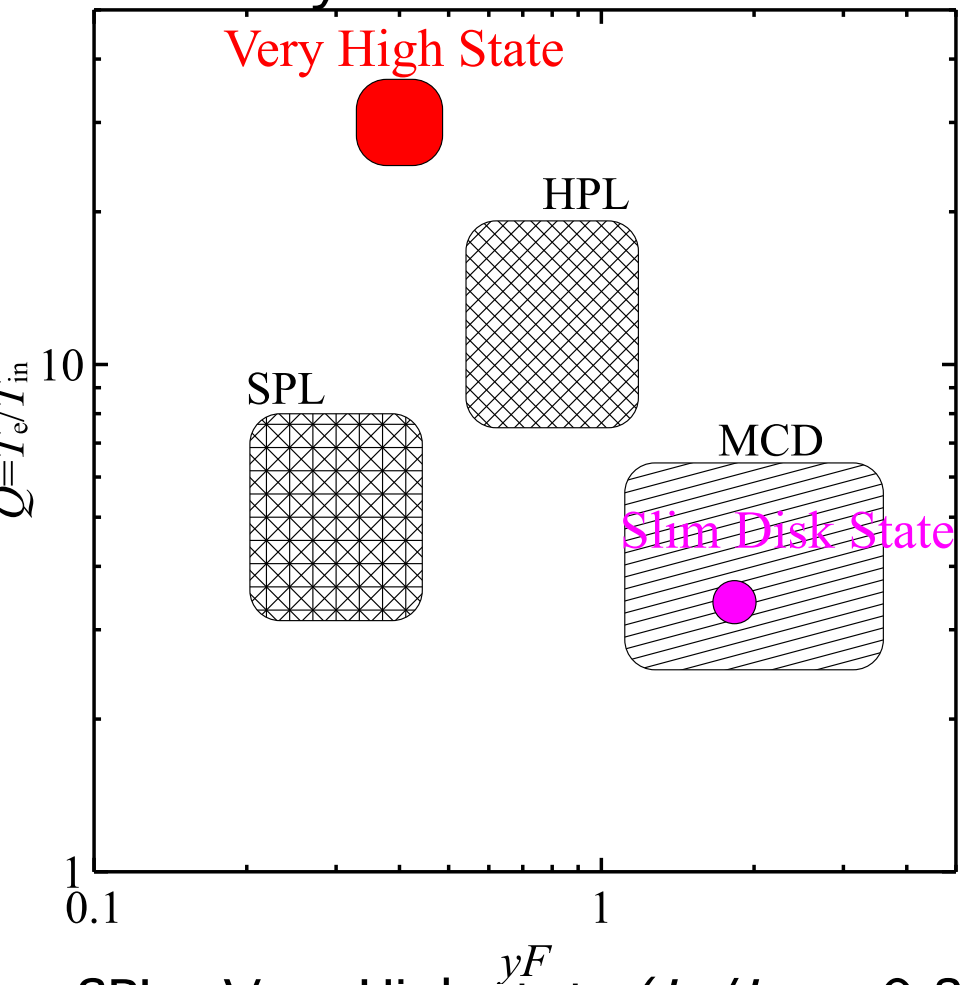


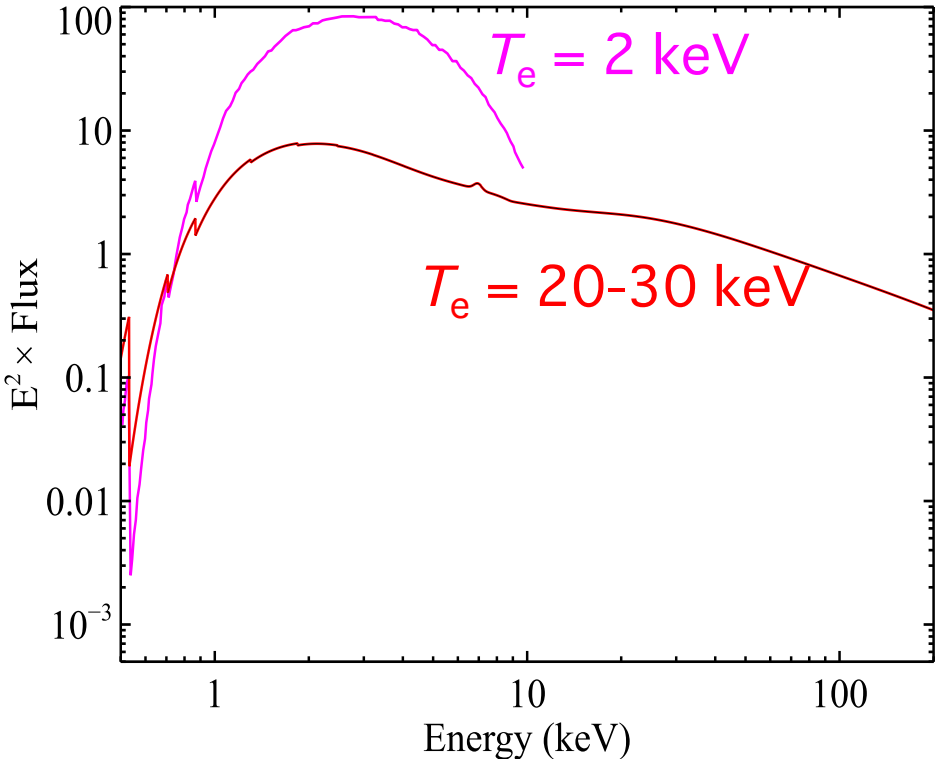


- The state-emerging luminosity scattered by a factor of 20.
- If the general properties of the accreting objects are also held in ULXs, then their BH mass should also have similar range.
- If we assume 10 $M_\odot$ as the minimum, the maximum will reach 100 $M_\odot$

B. Estimation of the Accretion Regime

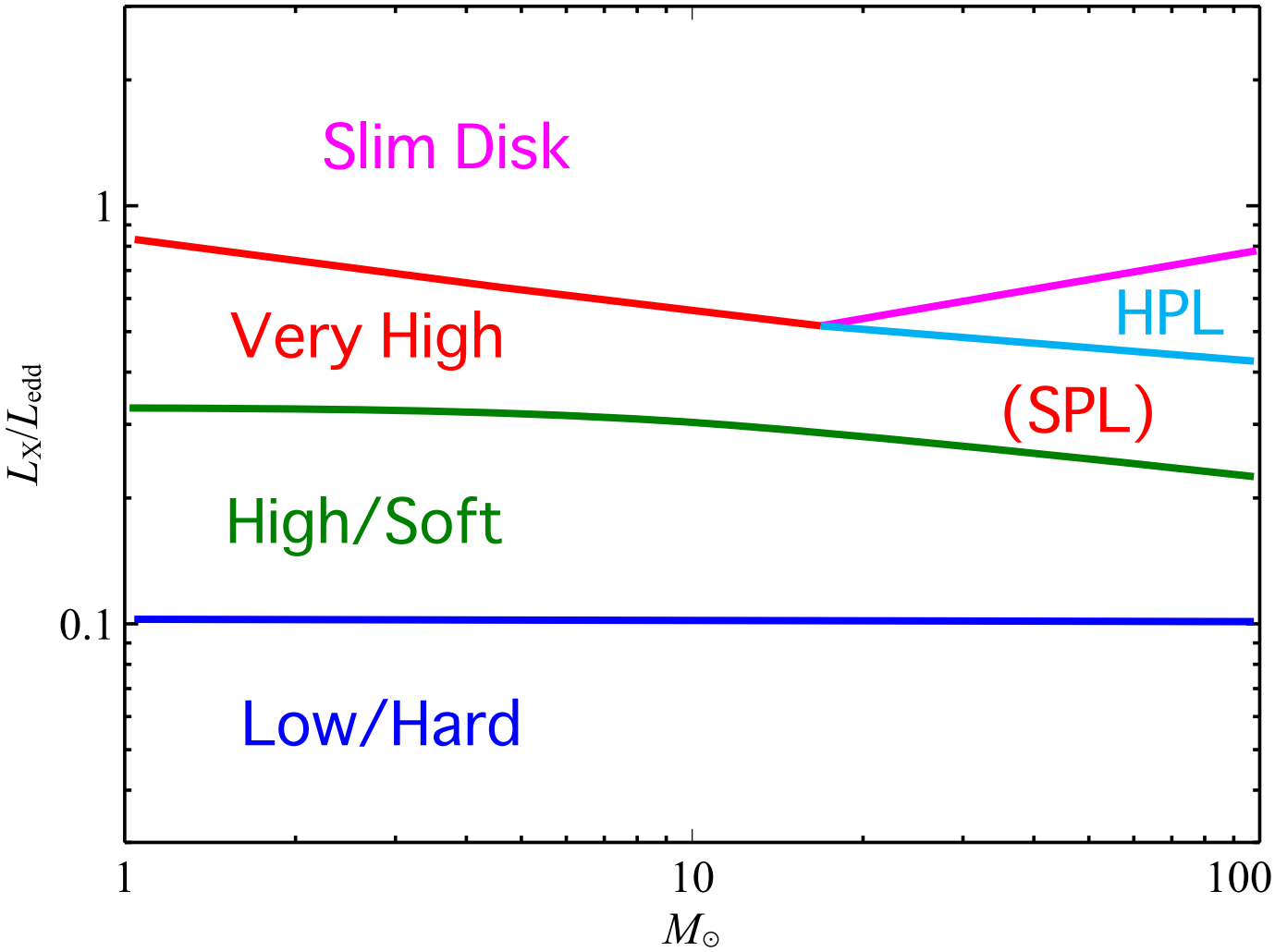
- How do the three states of ULXs correspond to those of the ordinary stellar mass BHBs?





- SPL→Very High state (L_X/L_{edd} ~0.3) , MCD→Slim Disk state (L_X/L_{edd} ~1).
- HPL→ a unique state of ULXs?

B. Phase Diagram in spectral states of BHs



- The spectral states of BHs might not be uniquely determined by L_X/L_{edd} but also with their masses.

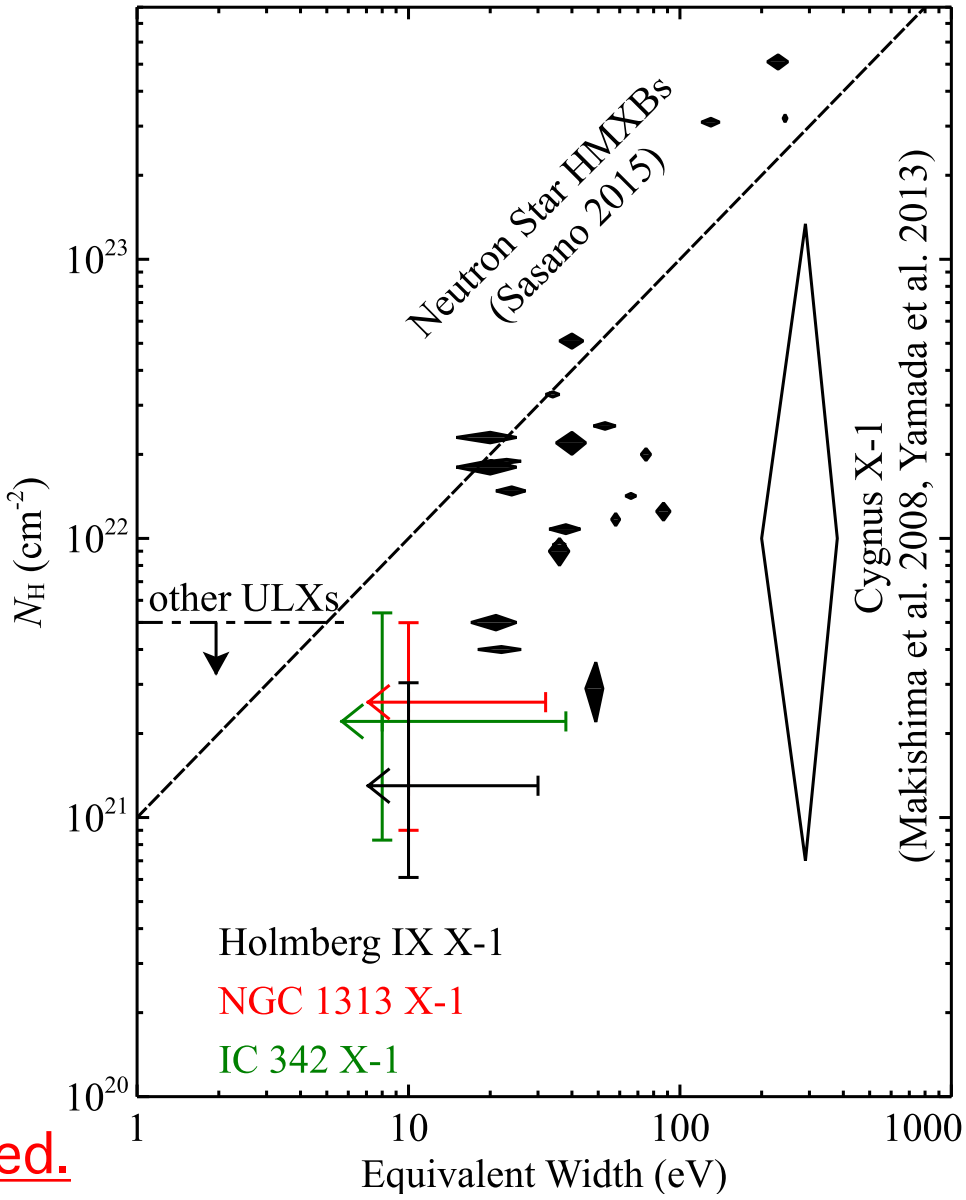
C. Estimation of the Accretion Environment

Comparison with High Mass X-ray Binaries (HMXB)

- ULXs are often considered as binary systems with high-mass companion (HMXB).
- N_H in ULXs are smaller and more stable than those in HMXBs in our Galaxy.
- Strength of Fe-K line is weaker than the HMXBs, as well.
- Matters surrounding ULXs should be poor.

ULXs are unlikely to harbor high-mass companion stars.

A new accretion scenario is required.



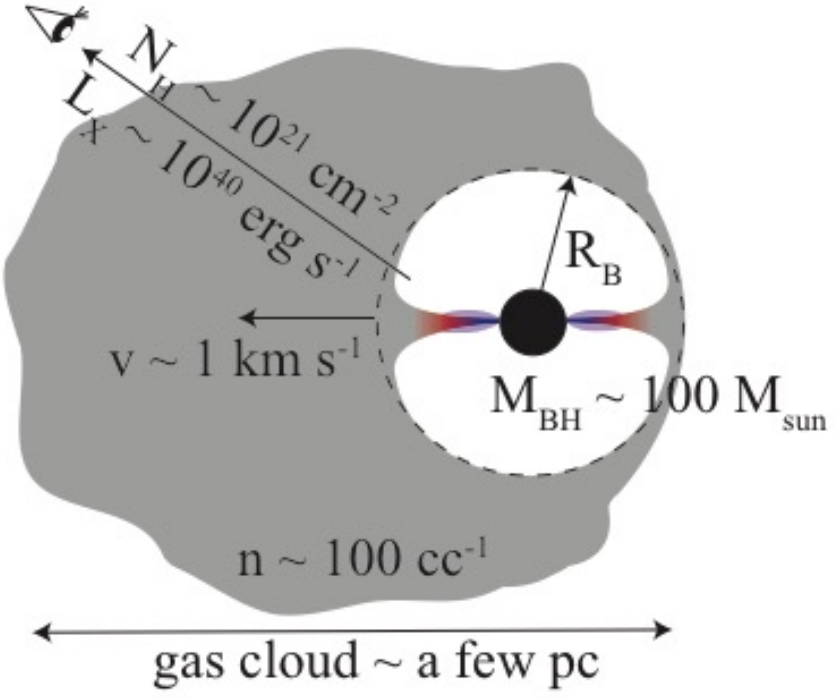
C. Possible Accretion Mechanism

Conditions to be fulfilled

- Central BHs are relatively massive.
- Surrounding matters that account for the Fe lines/absorption are poor.
- Sufficient mass accretion rate to sustain $L_X \sim 10^{40}$ erg/s.

Bondi-Hoyle accretion onto BHs (Mii & Totani 2005)

- Consider an isolated BH with a mass M_{BH} entering an interstellar medium with velocity v.
- The BH will accrete mass within a range of Bondi-radius which yield $L_X \propto M_{BH}^2 n v^{-3}$
- Fe-K line is expected to be ~10 eV.
- $L_X \sim 10^{40}$ erg/s, $N_H \sim 10^{21}$ cm^{-2} assuming typical density/size for gas cloud and relatively slow entering velocity (Nakamura+16).



Conclusions

- 56 spectra of 9 representative ULXs are analyzed.
- All of the spectra were successfully explained with MCD+THC model.
- The state emerging luminosity scattered over a range of 20 among the present ULX sample, suggesting BH mass have also similar range.
- Fe-K lines in ULXs are weaker than 30 eV and absorption was small and stable as $N_H \sim 10^{21}$ cm^{-2}.
- ULXs are unlikely to harbor massive companion star.
- Possibly they are isolated BHs which are directly accreting the surrounding interstellar medium.